# SELECTION OF PORTFOLIOS OF ELECTRICITY GENERATION PROJECTS: AN EXPLORATORY STUDY

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**Abstract:**

The electricity planning traditionally relies on optimization models with the objective of minimizing system costs. However, the liberalization trend of the market and development of renewable energy increased the complexity of this planning exercise. It becomes then necessary to study other methodologies in order to include in the planning process the risk variables and potential correlation between technologies and fuels. The main guidelines of current energy policy in Portugal should meet the goals of energy efficiency, reduce energy dependence without compromising security of supply, minimizing the environmental impact and promoting renewable energy development. In a scenario of high growth of renewable energy sources (RES), it is pertinent to study the seasonality of electricity production by the various RES (biomass, hydro, wind, solar ...) evaluating the potential complementarily between these sources as a mitigation or increase risk factor. As for thermal power plants, the existence or not of correlation between fossil fuel prices must also be considered. The risk-return approach is often used in the selection of financial assets, however, several studies have revealed its potential when applied to electricity planning, especially with regard to the inclusion of RES projects. This study will test the possible application this model for the Portuguese electricity system, resulting in the proposal of future scenarios for the electricity generation sector taking into account the increasing importance of RES.

**Keywords:** Electricity planning; Renewable Energy; Risk; System Optimization.

# 1. INTRODUCTION

According to DGEG (Direcção Geral de Energia e Geologia), Portugal is heavily dependent on foreign sources of energy, particularly oil. However, this trend has been declining due to increasing installed capacity of renewable energy. At the same time, due to successive increases in the price of primary energy, the costs with energy imports increased between 2009 and 2010. In Portugal, hydro and wind are the main natural resources used for electricity generation. Currently, these two RES represent more than 60% of the total installed power of the Portuguese electricity system. The development of RES based technologies to generate electricity can represent a key strategy for reducing dependence on foreign energy, contributing also to increased security of supply of electricity to consumers (DGEG, 2012).

The electricity and heat production activities are responsible for almost 20% of total primary energy consumption in 2011. Also, 55% of electricity consumption in Portugal has origin in importations, namely imported fossil fuel and imported electricity from Spain. The production of electricity is, then, the largest consumer of primary energy in Portugal (DGEG, 2011).

Table 1 shows the evolution, in the last three years, of the installed capacity of each technology for electricity generation in Portugal, based on data collected from REN (the Portuguese electricity grid operator).

**Table1: Installed capacity evolution, Source: REN**

| INSTALLED CAPACITY (MW) | | | |
|---|---|---|---|
| | **2009** | **2010** | **2011** |
| **Gas** | 2992 | 3829 | 3829 |
| **Coal** | 1756 | 1756 | 1756 |
| **Large hydro** | 2160 | 2397 | 2397 |
| **Run of river** | 2023 | 2583 | 2583 |
| **Small hydro** | 395 | 410 | 412 |
| **Onshore wind** | 3357 | 3705 | 4081 |
| **Solar PV** | 95 | 122 | 155 |

According to Table 1, wind power role has been increasing during the last years and in 2011 the installed power overpassed 4 GW. From the table, one can see, also, that there is also a slight expansion in solar technology. Table 1 also shows that the three hydro technologies sum up currently an installed capacity of nearly 5.5 GW, representing more than 30% of the total electricity power installed in Portugal. Therefore, hydropower has a key role in the National Electricity System (NES) management. As so, an extremely dry year can cause a significant increase in the production of electricity resourcing to fossil fuels and consequently impacting importation levels of these products. Moreover, a rainy year should result in lower importations of fossil fuel products to be used for electricity production.

Figure 1 shows the contribution of each technology to supply the electricity demand between 2009 and 2011 in Portugal. In 2009, the total consumption of electricity in Portugal was 49.9 TWh. The hydroelectricity production supplied 14% of consumption, whereas thermal energy sources supplied 47% of the total electricity consumption in Portugal. Special Regime Production (SRP) includes renewable power producers (excluding large hydro) and cogeneration. These SRP supplied 29% of consumption, of which 15% was due to wind-power. The import/export balance stood at 9%.

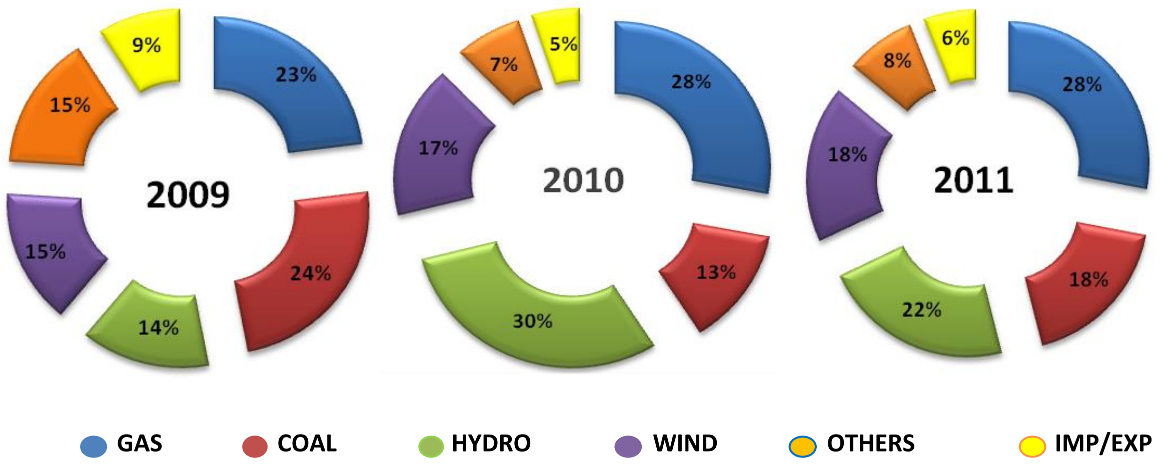


**Figure 1: Sources of electricity supply over the last 3 years (Source: REN)**

In 2010, electricity consumption increased to 52.5 TWh. The hydroelectricity sector supplied 28% of total consumption due to an higher than average hydroelectricity productivity index (HPI), which was 1.31 according to REN. The SRP supplied 34% of the consumption of which 17% were due to the wind power, which increased 20% over 2009 due to the construction of new parks and a higher than average wind production index (WPI) was 1.08. Thermal power plants supplied 33% of the electricity demand, the lowest share in 30 years. The import/export balance was the lowest since 2002, registering a supply of only 5% of total consumption (REN, 2010). These numbers show that this was a year extremely favorable to the production of electricity through renewable energy, mainly due to the higher HPI, compared to the other years of the study. For this reason, several stops from coal plants happened this year and there was, also, a decrease in electricity production through gas, especially during winter periods.

Finally, in 2011, electricity consumption was 50.5 TWh. The RES production supplied 46% of the total electricity consumption (wind 18%, hydro 22%, and other RES 6%) lower than the 52% share of the previous year. The HPI and WPI were below the average, 0.92 and 0.97, respectively. Moreover, the wind production decreased compared to the previous year, despite the increase in installed capacity of 375 MW. The thermal power production increased 12% and supplied 38% of total electricity demand (gas 28% and coal 18%). The import/export balance, in turn, increased, and represented 6% of total demand (REN, 2011).

The environmental pollution and energy dependence are major concerns of the European Union (EU), driving measures to reduce $CO_2$ emissions to satisfactory levels. The challenge is to generate "clean" and efficient energy within European borders in order to reduce environmental pollution and energy dependency. Development of renewable energy in Portugal was driven by a favorable environment, namely the stated Portuguese government goal of a sharp increase of electricity generation from RES sources and to enhance energy efficiency. This objective was accomplished through economic incentives for the installation of electricity generators from renewable sources coupled with technological developments. Finally, according to Deloitte (2009) report the Portuguese weather conditions are clearly favorable to the production of electricity through renewable energy sources, particularly hydro, solar, wind and even wave power.

## 2. THE MEAN-VARIANCE APPROACH (MVA) FOR ELECTRICITY PLANNING

### 2.1 Brief History of MVA

The MVA approach has its roots on the seminal paper of Markowitz (1952). The major objective of this approach is the selection of investment portfolios based on maximizing the value of future expected return within a certain level of risk the investor is willing to assume for its investment (Ferreira, Cunha 2011). With this approach it is possible to identify minimum variance portfolios for any level of expected return.). According to Markowitz (1952), the portfolio selection process can be divided into two stages. The first starts with observation and experience and ends with a perspective on the future performance of available securities. The second stage begins with the perspective on the future and ends with the selection of a portfolio of assets. Any investor in securities should maximize the return on its investment within acceptable risk levels. Risk and return, typically, have a positive correlation with each other. When the former increases the latter also increases. Therefore, the greater the risk, the greater the return of investment. However, Markowitz (1952) emphasized that diversification can reduce portfolio risk to lower levels, and this will depend on the correlation between assets within a given portfolio. Therefore, when deciding on their investments, investors should consider, in addition to the expected return, the dispersion of returns around the mean, i.e. the variance. Thus, the characteristics of an investment can be measured using the variables expected return and variance (Ferreira, Cunha 2011), and this is due to the fact that the distribution of expected returns follows a normal distribution. Therefore, assuming that a particular investor is risk averse, with a choice between two investments with the same standard deviation but different expected returns, it will always decide who is at higher expected return. So, instead of investing in a single financial asset, the investor should choose to invest in portfolios consisting of various assets. There are two main reasons why diversification reduces investment risk. On the one hand, as each asset included in a given portfolio represents only a small part of the capital invested, any event that affects one or some of these assets has a much more limited impact on the total value of the investment. Moreover, the effect of specific events on the value of each asset within the portfolio can be positive or negative. In large and diversified portfolios, these effects tend to offset each other without affecting the overall value (Ferreira, Cunha 2011).

### 2.2 MVA applied to electricity planning

In this paper, the intuition underlying the MVA approach is applied to the selection of portfolios of electricity generation technologies. By including as a decision variable the risk of portfolio (in this case the production costs of electricity), this approach allows policy makers or private investor integrating the three main objectives of energy policy in a quantifiable manner (McLoughlin, Basilian 2006): Energy at competitive prices; security of energy supply; mitigation of environmental impacts.
In recent years there has been an increasing application of the MVA approach to electricity planning in many countries such as Ireland (McLoughlin, Basilian 2006), Italy (Arnesano et al 2012) and Japan (Bhattacharya, 2010). In fact, the mean-variance model can be used to estimate optimal portfolios of electricity generation both for a company and for a country (Ferreira, Cunha 2011). As emphasized by Awerbuch (2003), energy planning is no different than investing in financial securities, where efficient portfolios are widely used by investors to manage risk and improve performance. Thus, energy planning should be focused to develop portfolios with efficient production than on finding alternatives with lower cost of production, because, at any given time, certain alternatives may have high costs and others may have lower costs. However, over time, a favorable combination of alternatives may facilitate minimizing the overall cost of production compared to the risk (Awerbuch, 2003).
Apart from the fact that it can find the optimal portfolio, the application of MVA allows analyzing the impact of the inclusion of renewable technologies (RES) in the scenario of generating sources of electricity. In particular, the MVATP allows a better assessment of the risk associated with the different technologies. Moreover, it allows, also, to illustrate the trade-off between production costs and risk, which means that it is not possible to achieve a lower cost of production of electricity, without assuming higher levels of risk (Ferreira, Cunha 2011).
Awerbuch (2003), in the analysis of power (or energy) systems, was able to model a combination of political, environmental and technological aspects. The inclusion of this aspects and, particularly, environmental concerns, has demonstrated that producing electricity through renewables is a strategy conducive to positive effects on the environment. In fact, Awerbuch (2003) demonstrated that the introduction of RES technologies (as wind, solar and hydro) in the energy portfolio, significantly reduces the total cost of energy and the production risk, since solar and photovoltaic technologies are risk-free, since its operation is not correlated with the change in the price of fuel (Arnesano et al 2012).

### 2.3 MVA applied to the Portuguese case

Electricity production investments in Portugal have been focused, mainly, in renewable energy sources. This focus, beyond the issue of economic and energy self-sufficiency, follows the guidelines of the EU towards reducing $CO_2$ emissions into the atmosphere, which justifies the decline of production of electricity through coal, despite the stability of its price in recent years. The frequent indexation of the price of non-renewable energy to oil prices and the concerns about fuel diversification and security of supply, led to the adoption of new technological solutions in the supply of electricity throughout the country.
The cost production of electricity depends on the technology and primary energy source used. In the case of thermal or non-renewable energy sources, the most relevant factor in calculating the cost associated with the production of electricity is the price of fuel

that is subject to market fluctuations. In the case of renewable sources, the critical component for calculating the associated cost is the capacity factor (CF) – the ratio of actual power produced and the power the generation plant could produce. The reason is that the initial investment is high and the marginal cost is very low. Therefore, the return on investment comes only within a reasonable period of time if the natural resources permit (Arnesano et al 2012).

Thus, for each technology, the respective levelised cost of electricity (LCOE) was calculated, which represents the total cost per MWh produced throughout the life of a plant and which can be obtained from the following expressions:

$$LCOE = \frac{\sum I_t + (M_t + F_t + X_t)\frac{(1+r)^t - 1}{r(1+r)^t}}{E_t . n} \qquad (1)$$

Where,
*$I_t$ = Investment cost*
*$M_t$ = Operation and Maintenance costs*
*$F_t$ = Fuel costs*
*$X_t$ = Environmental costs*
*n = Lifetime of the plant*
*$E_t$ = Power output*
*t = time period under study*

The investment cost was estimated from values related to constructions of various electricity generation plants, published by the International Energy Agency (IEA, 2010).

The operation and maintenance costs are all expenses inherent in the process of producing electricity and maintenance of equipment such as labor or material costs and, like the investment costs, in this study, were obtained from the publication of the IEA (2010). These costs may be fixed, as is the case of labor costs, and, if appropriate, maintenance contracts, or variables, namely costs which usually vary with the production, usually coupled with fatigue equipment or any necessary modifications in the equipment according production. The cost of fuel, naturally, only applies to thermal production technologies (coal and gas). The price of natural gas was obtained through the database "Datastream, Thomson Reuters" and is expressed in €/MWh. For this work we used the daily values. In the case of coal, the price of this raw material was obtained through the source "EUROPEAN COAL: CIF ARA". The environmental costs refer to the amount paid by the operator of the power plant relative to the amount of $CO_2$ released into the atmosphere and, as the price of coal, was obtained by database "Datastream, Thomson," coal price column. The lifetime of the plant corresponds to the average life time (in years) estimated for all power plants corresponding to each technology. In this study, we used values published by IEA (2010) and Moot MacDonald (2010).

Figure 2 shows the mean values of the power output for each technology over the last 3 years, computed from REN data.

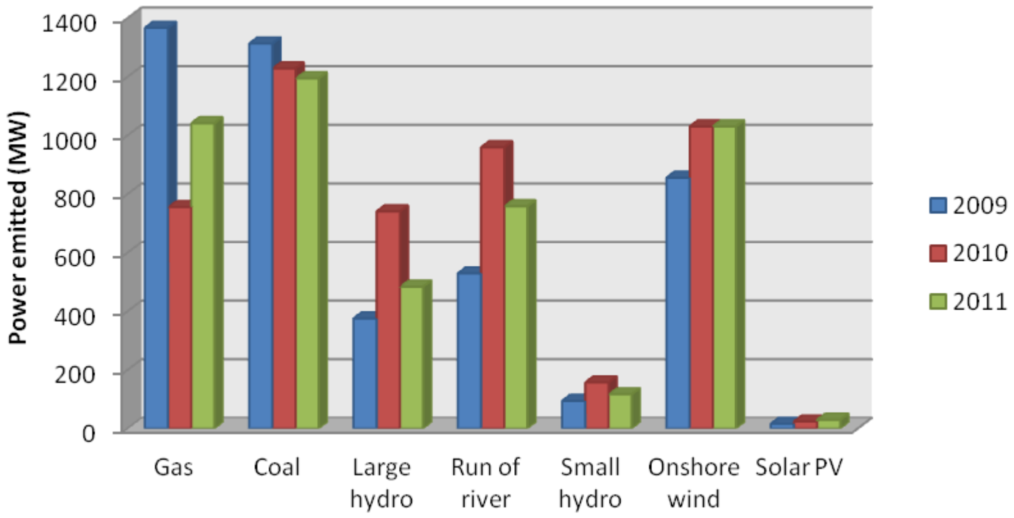


**Figure 2: Mean power output for each technology 2009-2011. Source: REN.**

Table 2 shows the evolution of the LCOE over the three years for all technologies included in this study. These values were by applying the equation (1) using the data from the sources described above.

**Table2: Levelised Cost of Electricity over the three years (average values)**

| Levelised Cost of Eletricity (€/MWh) | | | |
|---|---|---|---|
| | **2009** | **2010** | **2011** |
| **Gas** | 69,30 | 131,97 | 115,37 |
| **Coal** | 57,90 | 75,29 | 85,24 |
| **Large hydro** | 88,49 | 64,87 | 79,17 |
| **Run-of.river** | 108,71 | 76,66 | 88,94 |
| **Small hydro** | 120,61 | 91,48 | 107,07 |
| **Onshore wind** | 68,31 | 62,43 | 65,42 |
| **Solar PV** | 218,19 | 173,55 | 174,88 |

## 2.4 Simulation of Optimization Model

Markowitz (1952) showed that in order to maximize the expected return on any investment, and at the same time minimizing the associated risk, the investment should be diversified into more financial assets. Therefore, all assets considered in portfolio analysis should be characterized not only by the expected return but also by their variability, measured as the variance (or standard deviation) of expected returns. Investment diversification is effective in maximizing expected return while minimizing risk since the evolution of assets' prices are not perfectly correlated. One can say that a portfolio is efficient if there is no other portfolio with the same variance and higher expected return, or if there is no other portfolio with the same expected return and lower variance. Therefore, the efficient frontier is the set of efficient portfolios (Arnesano et al 2012).

Although, the MVA approach has been extensively applied in a financial context, in order to estimate the portfolio risk and expected return , it is also possible to use it for the selection of portfolios of electricity generation technologies (Bhattacharya, 2010). In this context, costs are quantified as generation costs and the return is measured by the inverse of those costs (Awerbuch, 2003).

The expected return of the portfolio is expressed by the weight of each technology's return in the portfolio and can be calculated by equation (2).

$$E(R_p) = \sum_{i=1}^{N} W_i E_{(Ri)} \qquad (2)$$

Where $E_{(Ri)}$ represents the value of the expected return from the $i_{th}$ technology ($R_i$), and $W_i$ is the share of the ith technology in the portfolio.

The inverse of the LCOE for each technology serve as a proxy measure of return of a physical output per monetary unit as input (Awerbuch, 2003). In other words, lower cost means higher outcomes associated to the production of electricity using the same technology (Arnesano et al 2012).

$$R_t = \frac{1}{LCOE_t} \qquad (3)$$

Where ($R_t$) is the return in period t, and ($LCOE_t$) is the cost in period t for a given technology.

The risk of the portfolio, E ($\sigma_p$), is represented by the standard deviation of the portfolio ($\sigma_p$) measured by variations on the LCOE. The risk associated with the portfolio is calculated by equation 4.

$$E_{(\sigma p)} = \sqrt{\sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sum_{j=1}^{N} w_i w_j cov_{ij}} \qquad (4)$$

Where,

$i \neq j$; i=1,2,3,…,n; j=1,2,3,…,n; $w_i$ and $w_j$ are the variables which represent the corresponding weight technologies i and j respectively, in the portfolio; $\sigma_i$ represent the standard deviation of the rate of change of cost and $COV_{ij}$ is the covariance of two technologies as can be seen in equation 5.

$$cov_{ij} = \rho_{ij} \sigma_i \sigma_j \qquad (5)$$

$\rho_{ij}$ is the correlation between technologies i and j, which characterizes the diversity within the portfolio. The lower the value of $\rho_{ij}$ between portfolio's technologies the higher the portfolio's diversity and, consequently, contributes to a reduction in portfolio's risk, $E_{(\sigma p)}$. In other words, increasing the diversity of the portfolio, by adding technologies uncorrelated or correlated negatively, reduces the risk of the portfolio, which can be observed by the tendency of correlation to zero (Bhattacharya, Kojima 2010).

For the calculations REN data was used, representing the power output for each technology measured for each quarter of an hour for the period 2009-2011. This level of data detail is particularly important as is it allows capturing de variability and seasonality of RES. Table 3 describes the correlation between different technologies obtained from these time series.

**Table 3: Correlation between different technologies**

| | Coal | Large hídro | Run of river | Small hydro | Onshore wind | Solar PV |
|---|---|---|---|---|---|---|
| **Gas** | 0,0631 | 0,0378 | 0,0490 | 0,0399 | -0,0541 | 0,0101 |
| **Coal** | | 0,0600 | 0,0427 | 0,0198 | -0,0975 | -0,0034 |
| **Large hídro** | | | 0,1641 | 0,0750 | -0,0652 | 0,0107 |
| **Fio-de-agua** | | | | 0,0834 | -0,0388 | 0,0099 |
| **Small hídro** | | | | | -0,0174 | 0,0339 |
| **Onshore wind** | | | | | | -0,0440 |

Once the covariance between different technologies is determined, the first objective function of this model is to minimize the investment risk of a given portfolio of electricity generation technologies, as given in equation 4. Assuming that a particular portfolio is comprised of *n* different technologies, the optimization problem can be solved by equation 6.

$$\text{Minimize } \left(\mathrm{E}(\sigma_p)\right) Min = \sqrt{\sum W_i^2 \sigma_i^2 + \sum(w_i w_j cov_{ij})} \qquad (6)$$

*Subject to*

$\sum w_i = 1;$

$Wi \geq 0;$

After calculating the lowest risk portfolio, to be increased the risk, the efficient portfolio will be found. The second objective function (Equation 7) is used in order to maximize the expected return without exceeding risk assumed, ie:

$$Maximize\ E_{(r_p)}\ Max = \sum_{i=1}^{N} w_i E_{(r_i)} \qquad (7)$$

Subject to,

$$\sigma_p^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} w_i w_j \sigma_{ij} \leq \sigma^2$$

$$\sum_{i=1}^{N} w_i = 1$$

$$w_i \geq 0$$

Solving equation 7 for different levels of expected return, different portfolios of technologies are obtained. Table 4 shows some examples of these portfolios.

**Table 4: Energy solutions portfolios with different risk levels**

| Portfolio | A | B | C | D |
|---|---|---|---|---|
| **RISK** | **0,015** | **0,030** | **0,060** | **0,120** |
| **W (coal)** | 25,5% | 9,2% | 0,0% | 0,0% |
| **W (gas)** | 16,0% | 12,9% | 0,0% | 0,0% |
| **W (Large hídro)** | 1,8% | 16,4% | 38,2% | 100,0% |
| **W (fio d'água)** | 3,0% | 15,4% | 26,5% | 0,0% |
| **W (Small-hídro)** | 21,0% | 8,6% | 0,0% | 0,0% |
| **W (Wind)** | 29,2% | 19,4% | 0,0% | 0,0% |
| **W (Solar)** | 3,4% | 18,1% | 35,4% | 0,0% |
| **E(rp)** | **0,00076** | **0,00235** | **0,00435** | **0,00585** |

Table 4 shows the convergence to a solution composed of 100% electricity production through large hydro. From Table 4 it becomes evident that lower risk solutions are the ones with a more diversified portfolio. The return of the portfolio can increase for less diversified solutions relying mainly on RES technologies but the risk increases, which can be justified by the variability and seasonality of the renewable resources.

The set of portfolios that result from this process and that forms the efficient frontier is shown in Figure 3.

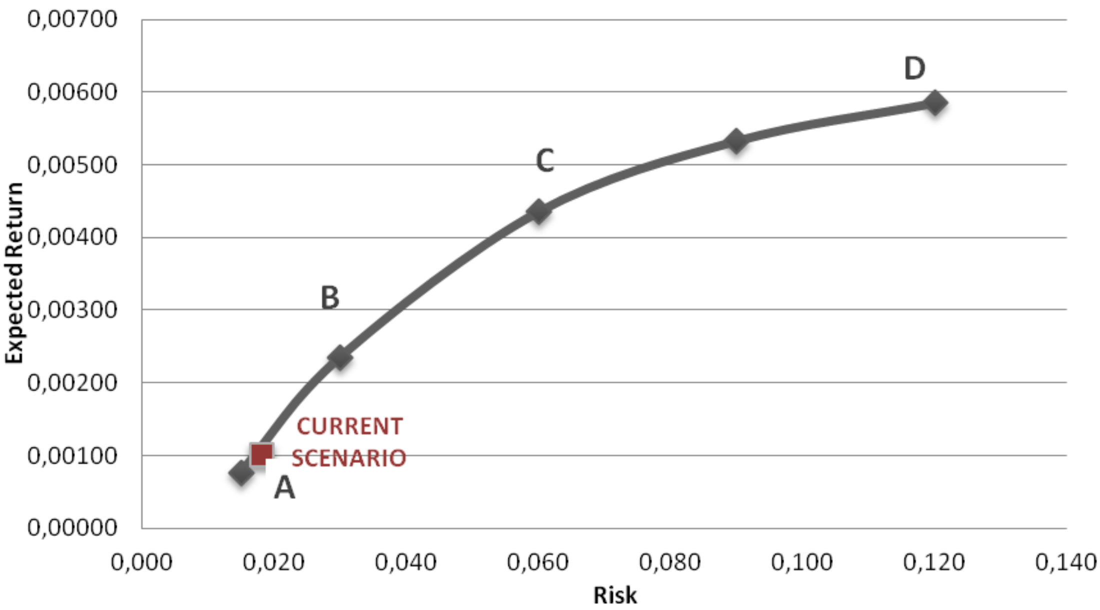


**Figura 3: Comparison between the solutions presented by the MTP and the current scenario of REN**

Each point on the efficient frontier represents a portfolio with maximum expected return for a given level of risk or minimum risk for a given level of return. The Portfolio A: Portfolio with lower risk, but lower expected return. Normally there is more diversity in their assets; Portfolio B: Portfolio with expected value higher than the A, however, increases the risk associated. Typically, there is less diversity in their assets. Portfolio B presents a very small proportion of thermal energy, the result of increased weight of hydropower, which is only possible in rainy periods, and by photovoltaic that in this solution has 18% (table 4) of the total electric power issued for NES. The portfolio C, is composed only by the photovoltaic and hydropower, so this scenario is considered very hard to implement, since, currently. Finally, the portfolio D, presents a scenario composed of 100% large hydro, allowing to obtaining the maximum expected return utilizing the large hydro to produce all electricity in Portugal. It should be underlined that this MVA approach does not take into account the technical feasibility of the proposed portfolios, as no constraints were imposed for these matters.
Figure 2 also shows at what point of the efficient frontier is located the combination of current technologies for producing electricity, in terms of risk and expected return, respectively. The current scenario presents a very low risk and of course, an expected low return. Therefore, the current Portuguese portfolio of technologies to generate electricity is on the efficient frontier and near Portfolio A.

## 3. CONCLUSIONS

This paper presents an approach to electricity power planning in a system with strong RES influence and, as so, highly dependent on the seasonality and variability of the renewable resources. If from one side, RES based technologies are recognized to have low marginal costs, their high capital costs and the uncertainty of their output are major drawbacks to their effective implementation. The MVA use on the definition of electricity portfolio was tested and revealed to be a valuable tool for energy decision makers. It allows to explicitly dealing with the cost aspects, by resourcing to the LCOE for the return computation, and with the variability of the system, by including the risk element in the analysis.

MVA presents itself as a very powerful tool in the decision making of financial investors, taking into account the risk that each is subject to assume a given investment in the stock market. However, the results of this model have several limitations when applied to electricity generation that should not be overlooked.

The stock market's financial sector is constantly marked by the rise and fall of their respective values and what makes them more or less risky an investment in the stock market is the dispersion of possible outcomes, a value that is measured by the standard deviation. What happens in the stock market is that their greater profitability happens when they value increases; the same is not true in situations stagnant stock price. The model applied in this work translates exactly this variability and presents the results in terms of maximum expected return and minimum variation. However on the NES, greater stability is not always an advantageous if the output values are very low. For NES the return will be much higher in a situation with high output values, even with a decreasing trend, than in a situation of low output values with an increasing trend. That is to say, the objective should be to ensure the high outputs for the longest possible period. Also, the technical feasibility of the portfolios and the RES potential must be also include in the model in order to ensure that the solutions can in fact be implemented. This means that future work must focus on the development of a modified MVA model where new return and risk variables are to be defined and additional restrictions are to be included, according to the technical characteristics of the electricity problem under analysis.

Nevertheless, this exploratory exercise allowed to clearly demonstrate the need to include the risk variable on the electricity planning and to take into account the existence of correlations between RES underlying resources and consequently on their output.

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